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VECTORCARDIOGRAPHIC RESULTS OF HUMAN EXPOSURES TO +3GZ, +5GZ, A--ETC(U)

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# VECTORCARDIOGRAPHIC RESULTS OF HUMAN EXPOSURES TO $+3G_z$, $+5G_z$, AND $+7G_z$



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Final Report for Period August 1975 - December 1979



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## NOTICES

This final report was submitted by personnel of the Biodynamics Branch, Crew Technology Division, USAF School of Aerospace Medicine, Aerospace Medical Division, AFSC, Brooks Air Force Base, Texas, under job order 7930-12-21.



The voluntary informed consent of the subjects used in this research was obtained in accordance with AFR 80-33.



This technical report has been reviewed and is approved for publication.

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Frank orthogonal vectorcardiograms (VCG) were recorded from 10 subjects before, during, and for 15 min after exposures to $+3G_z$, $+5G_z$, and $+7G_z$. The order of acceleration exposure was randomized, with the individual exposures separated by at least one week. Standard USAF anti-G suits were worn by all subjects. Detailed analysis of the scalar lead electrocardiograms revealed no abnormalities and no consistent signs of conduction disturbances or ischemic ST-T segment changes. During $+G_z$ stress, the QRS axis of the VCG demonstrated

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20. ABSTRACT (Continued)

posterior rotation in the sagittal plane, and counterclockwise rotation in the transverse plane. The changes in the VCGs recorded during $+G_z$ stress appeared to be related to rotational changes of the heart due to mechanical stress and/or motion within the thorax. There were no ECG or VCG changes indicative of myocardial ischemia and/or damage during or after $+G_z$ stress. Comprehensive data obtained in this study are presented here.

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# VECTORCARDIOGRAPHIC RESULTS OF HUMAN EXPOSURES TO $+3G_z$, $+5G_z$, AND $+7G_z$

## INTRODUCTION

The major benefit of the vectorcardiogram (VCG) is that it allows visualization of the electrical forces of the heart in a three-dimensional manner. The VCG also provides a better view of the posterior electrical forces of the heart than does the standard electrocardiogram (ECG), and therefore can be used to make some diagnoses which otherwise might be missed. Thus, interpretation of the ECG can often be enhanced by vectorcardiographic techniques, and vice versa (10, 11). In studies of acceleration stress, VCG analyses are especially valuable because they can give an increased appreciation for the G-induced mechanical displacements of the heart within the thorax.

Several investigations of the effects of $+G_z$ acceleration on human ECGs have been conducted (2, 7, 8, 18). However, few studies have measured human VCGs during $+G_z$ acceleration (1, 9); and no studies have yet investigated the effects of acceleration levels greater than $+5G_z$. This report presents the results of VCGs recorded from 10 human subjects during and after 45-s exposures to $+3G_z$, $+5G_z$, and $+7G_z$ stress.

Since the initial observations of subendocardial hemorrhage and minor cardiomyopathy in miniature swine following exposure to $+G_z$ stress (5, 17), we have been trying to determine if similar lesions might occur in man (3, 4, 13, 14, 16, 19). Although existing data, collected from human subjects exposed to $+G_z$ stress, do not indicate the presence of cardiac pathology (13, 14), nonspecific T-loop changes have been reported in some VCGs recorded after $+G_z$ exposure in humans (14). These T-loop changes have not been consistently observed in various studies. Because the results of these previous studies are contradictory, the overall significance of the apparent G-induced VCG changes is difficult to assess. Therefore, the dual purpose of this study has been to expand the existing "during $+G_z$ VCG" data base to include recordings during $+5G_z$ and $+7G_z$ exposures, and to clarify the effects of acceleration exposure on VCGs in relation to possible $+G_z$-induced cardiac ischemia and/or damage.

## METHODS

VCGs were recorded from 10 male subjects, 19 - 35 years of age--with a mean age of 24.4 years. The subjects were members of the centrifuge stress panel at the USAF School of Aerospace Medicine (USAFSAM) and were, therefore, experienced centrifuge riders. All were healthy asymptomatic individuals, with no history of cardiac disease. They had recently passed a USAF Class III flight physical examination, which included a normal ECG, and normal postanterior (PA) and lateral chest radiographs.

Prior to $+G_z$ stress, the subjects were fitted with a standard USAF CSU-12/P anti-G suit. The pressure within the anti-G suit was controlled with an Alar MS24350-6 standard valve. The subjects were instrumented with silver-silver chloride "paste-on" skin electrodes. The electrodes were placed in accordance with the method described by Frank (9, 12). The Y-lead of the Frank lead system was placed over the anterior iliac crest to help minimize muscle artifacts during the M-1 or L-1 straining maneuvers. The recording-amplifier system used in these studies was in accordance with the standards of the Committee on Electrocardiography of the American Heart Association (6). The scalar leads (X, Y, and Z) were electrically transferred through the slip rings of the USAFSAM Human Centrifuge, displayed on a Brush Mark 200 direct writing recorder, and recorded on FM magnetic tape for subsequent reproduction and data analysis.

## Experimental Protocol

The subjects were placed in the centrifuge in a standard (13° back angle) USAF fighter-aircraft seat. After 15 min of baseline recording, each subject was exposed to a $+3G_z$, 15-s rapid onset ($+1G_z$/sec) "warm-up" profile, followed by a short rest period. After heart rate had returned to pre-G-stress levels, the subject was exposed to a rapid onset $+G_z$ profile for 45 s at a level of $+3G_z$, $+5G_z$, or $+7G_z$. Each subject was only exposed to one 45-s $+G_z$ exposure, after the "warm-up" run, on any given day. The order of acceleration exposures ($+3G_z$, $+5G_z$, or $+7G_z$) was randomized (Table 1) and each individual exposure separated by at least one week to minimize any possible cumulative G-stress effect.

The scalar leads were recorded for 15 min: before the $+3G_z$ "warm-up" run; during exposure to the "warm-up" run; immediately before and during the 45-s $+3G_z$, $+5G_z$, or $+7G_z$ run; and after the 45-s $+G_z$ profile. During the $+G_z$ exposures, the subjects were instructed to perform whatever straining maneuvers (M-1, L-1) were necessary to maintain peripheral vision.

## Data Analysis

All scalar-lead ECG recordings were inspected for dysrhythmias, wave-form changes, and the presence of any abnormalities during and after each $+G_z$ exposure of each subject. Each recording was reviewed by three different investigators.

Vectorcardiographic analyses were performed using computer-assisted digitizing, averaging, measurement, and display techniques which have been discussed in detail previously (15, 20, 21). VCGs were obtained: under resting control conditions (pre-G); during $+G_z$ stress; and at 1, 5, and 15 min after $+G_z$ exposures. The VCGs during $+G_z$ were taken at the 15-s point (early G), and for the last 10-s (late G) of each 45-s $+G_z$ plateau.

The scalar lead ECG data were reproduced from the analog FM magnetic tape digitized at 500 samples/s and were stored on digital magnetic tape for subsequent digital batch processing. The VCG parameters obtained in these studies

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EDITOR'S NOTE: For the convenience of the reader, all of the tables (Nos. 1-10) are grouped at the close of this publication.

were taken from an "average beat," which represented the average of 10 selected cardiac cycles taken at the points in time already discussed. Whenever possible, the "average beat" was obtained by averaging 10 successive beats. Graphic displays of each average beat and its respective vector loops were produced to assist in visualizing and evaluating the data. A total of 188 VCG parameters (angles, voltages, durations, slopes, etc.) were also printed-out in digital form (15) and accumulated in a data file for subsequent statistical analysis.

The order of presentation of G was randomized with the acceleration exposure scheme given in Table 1. Each subject underwent three exposures: $+3G_Z$, $+5G_Z$, and $+7G_Z$. For each exposure, VCGs were taken: before acceleration; twice during acceleration (designated "early" and "late" G); and at 1, 5, and 15 min postacceleration. The variables analyzed for this report are given in Table 2. Two of the 10 subjects did not complete the study and were omitted from all analyses. A significance level of 0.05 is used in this report.

A two-factor analysis of variance was performed to compare the preacceleration VCG data, in order to determine whether the subjects had returned to baseline values before another acceleration exposure had taken place. For the purposes of this test, the order of presentation of the various levels of acceleration, rather than the acceleration itself, is of importance; and so the analysis was performed placing each subject before acceleration VCGs in the time order in which the VCGs took place. While this order was being attained, one subject, RR, was exposed to +3G and +7G on the same day. RR's data were therefore omitted from this analysis. Significant differences were found between the order means in several variables. Table 3 gives the significance level for each variable. Where significant differences were found, Dunnet's procedure for comparing treatment means with a control was used to compare the second and third order means with the first order mean. Order one is before the first exposure to acceleration, while orders two and three are before the second and third exposures to acceleration. The results of these tests and the order means are given in Table 4. Of particular interest are the various trends in the order means. For example, the variables J Vector and M Vector, which showed significant differences in several planes, also showed an increase over order in all planes, with some increases being statistically significant. Trends may be due to many factors (for example, learning); however, the mechanisms responsible for these trends are unclear.

A three-factor analysis of variance--using time, G-level, and subjects--was performed to detect differences not only in response during and immediately after G but also in G-level. We expected differences in G-level to show up as such by time interaction in the absence of any order effect, for the preacceleration means would not be different; but the means, during and/or after acceleration, could be different. As might be expected, many indications of time differences were noted which were, for the most part, changes during actual exposure to G. Also many indications were noted of difference in response to G-level, as shown by a significant G-level by time interaction. In some cases (for example, Maximum T-Vector), this change was seen as a reversal at +7G; that is, while +3G and +5G tended to show a decrease in Maximum T Vector, +7G tended to show an increase during acceleration. The probabilities for time, G-level, and G-level by time interaction are given in Table 5. The mean values and the results of Dunnet's test of these values against the preacceleration means are given in Tables 6-10.

## RESULTS

Satisfactory scalar recordings were obtained from all 10 subjects. QRS complexes were qRS, qRs, and RS in the X, Y, and Z leads respectively, while T-waves were positive in all three axes. The effects of $+G_Z$ on the ECG, as reflected by the scalar leads, are presented in Tables 8 and 9. The $+G_Z$ exposure had no significant effect on QRS duration. No consistent electrocardiographic signs of conduction disturbances or ST-T segment changes were observed. The effects of $+G_Z$ stress on T-wave and Q-T interval durations varied in accordance with heart-rate changes. The T-wave duration remained prolonged for 15 min after exposure to $+5G_Z$, but not after exposure to $+3G_Z$ and $+7G_Z$. As shown in Table 9, heart rates were increased during all $+G_Z$ exposures, thus indicating a relationship between heart rate and $+G_Z$ level. Heart rates returned to control values immediately after $+G_Z$ stress.

### VCG Analysis

Satisfactory VCGs were obtained from all 10 subjects, with the exceptions shown in Table 1. The orientation of the QRS and T vectors is presented in Table 7. The results of the VCG analysis are presented in Tables 6, 7, and 10.

The effects of $+G_Z$ on the VCGs in the frontal plane are summarized in Tables 6 and 7. While the changes noted during $+G_Z$ in the true QRS angles were greater in magnitude than the maximum QRS angles, only the maximum QRS angle changes during $+7G_Z$ were statistically significant (Table 7). The maximum QRS voltage was significantly decreased during $+5G_Z$ and $+7G_Z$ stress (Table 6). The QRS loops had returned to "normal" 1 min after $+G_Z$ exposure. There were small maximum T-vector angle changes during $+G_Z$ which were not statistically significant. The maximum T-vector voltages showed significant decreases during $+3G_Z$ and $+5G_Z$ stress, with slight increases 1 min after $+G_Z$ stress. The maximum T-vector showed significant increases during $+7G_Z$, with even greater increases 1 min after $+7G_Z$ exposure (Table 7). The T and QRS vectors obtained 15 min after $+G_Z$ exposure were all identical to the respective baseline recordings.

Exposure to $+5G_Z$ and $+7G_Z$ stress resulted in decreases in the transverse plane maximum QRS vector angles; however, these angles were not significantly changed (Table 7). The QRS vector voltage was not significantly changed in the transverse plane during or after $+G_Z$ exposure (Table 6). Maximum T-vector voltage was significantly decreased in the sagittal plane during early $+G_Z$ exposure (Table 6). These voltage changes were not present during late $+G_Z$ exposure. Probably due to the large individual variability, there were no consistent or statistically significant changes in the sagittal plane vector angles (Table 7). Although large changes apparently took place in the maximum T-vector angles in the transverse plane, none of these changes were statistically significant. The only QRS-T angle change which was statistically significant was observed during early $+7G_Z$ exposure (Table 7). Significant decreases in transverse plane maximum T-vector voltage were observed during early $+3G_Z$ and $+5G_Z$ stress, while maximum T-vector voltage was significantly increased 1 min postexposure to $+5G_Z$ and $+7G_Z$ (Table 6).

## DISCUSSION

The dual purpose of this study was to expand the existing data base of VCGs recorded during $+G_Z$ to include data from $+5G_Z$ and $+7G_Z$ stress, and to continue investigation into the possiblity of $+G_Z$-induced cardiac pathology in man. Analysis of the resulting data revealed no evidence of cardiac pathology. Thus, these results agree with those from previous human studies which have found no evidence of cardiac lesions similar to those noted in miniature swine after $+G_Z$ exposure (9, 13, 14, 18).

### Scalar Electrocardiograms

Review of all the scalar electrocardiograms in this study revealed no significant abnormalities. Although $+G_Z$ stress is dysrhythmogenic, with an increase in dysrhythmias being directly related to increases in the level of $+G_Z$ (18), only a single premature ventricular contraction was noted during this entire study. The absence of more frequent and ominous dysrhythmias implies the absence of myocardial ischemia in man during $+G_Z$ stress.

In a recent study, VCGs were recorded from conscious miniature swine during and after exposure to $+G_Z$ (19). During the immediate postacceleration period, 4 of 6 swine manifested left ventricular ectopic beats. Other observed dysrhythmias included: atrial and junctional ectopic beats, J-point and T-wave alterations, and paroxysmal ventricular tachycardia. Since +G exposure appears to result in more cardiac dysrhythmias in miniature swine than in humans, $+G_Z$ exposure may produce more cardiac stress in these animals than in man. We believe that the miniature swine may not be manifesting pathology unique to $+G_Z$ stress, but may simply be exhibiting the porcine stress syndrome--as a result of the restraint stress and emotional stress involved in $+G_Z$ exposure (16).

The frequent occurrence of left ventricular septal wall involvement in subendocardial hemorrhage in miniature swine exposed to $+G_Z$ (5, 17) has led to the speculation concerning significant involvement of the cardiac conduction system in the cardiac pathology. One case of a conduction abnormality in a miniature swine during and after $+G_Z$ has been reported (5). In our experience with over 100 miniature swine, however, no other manifestation of interventricular conduction disturbances has been seen during $+G_Z$ exposure. Also, in the present study of human subjects, no scalar electrocardiographic patterns characteristic of fascicular or bundle branch block were observed. In addition, all conduction measurements (P-R interval, QRS duration, T duration, Q-T interval) varied appropriately with changes in heart rate, with no evidence of prolongation or conduction changes (Table 9).

Electrocardiographic indications of myocardial ischemia usually include ST-segment and T-wave changes. During maximal treadmill exercise stress testing, ST-segment depression is known to be highly associated with the presence of myocardial ischemia. No ST-segment depression or other significant alteration in the ST-segment was noted at any time in the scalar ECGs in this study. In other centrifuge work, the presence of ST-segment depression is very rarely observed, even in the clinical aeromedical population (18). The absence of ST-segment changes during $+G_Z$ is consistent with the absence of myocardial ischemia. Changes in T-wave amplitude are frequently observed during and after $+G_z$ stress in standard ECGs (1, 2, 7 - 9, 18). In this study, T-wave amplitude changes were also seen in the scalar leads, predominantly exhibited as decreased T-wave amplitude during $+G_z$, with increased amplitude and peaked T-waves after $+G_z$ stress. In most cases, the greatest increase in T-wave amplitudes occurred after exposures to higher $+G_z$ levels. The significance of these changes is not completely understood at this time.

## Vectorcardiograms

The baseline results of the present study are in good agreement with those of Cohen et al. (9) and are within normal limits (6). Cohen et al. (9) have used the Frank orthogonal lead system to study the effects of $+G_z$ on VCGs during acceleration exposures up to $+3.1G_z$. Exposure of our subjects to $+3G_z$ revealed no effect on QRS vector angles or magnitudes. This finding was somewhat surprising, because Cohen et al. (9) had reported a significant posterior shift of the maximum QRS vector in the transverse and sagittal planes during exposures to similar levels of $+G_z$. This difference in results may be related to the fact that the inflation of the anti-G suit caused a decrease in the inferior-posterior shift of the heart and diaphragm of our subjects during $+G_z$.

Exposure to $+5G_z$ caused posterior shifts in the maximal QRS vectors in both the transverse and sagittal planes. These shifts were slightly larger in magnitude than those reported by Cohen et al. (9) during exposure to $+3.1G_z$; however, the changes were not statistically significant.

The frontal plane maximal QRS vector magnitude was significantly decreased during exposure to $+5G_z$ and $+7G_z$. Although the cause of these changes is not known, they may be related to changes in the size and/or volume of the heart during $+G_z$ exposure (14).

The effects of $+7G_z$ exposure on the maximal QRS vector were quite variable and are therefore not easily interpreted. In the transverse plane, $+7G_z$ exposure resulted in a posterior shift in the maximal QRS vector which was greater than that noted during $+5G_z$ exposures. During the first 15 s of $+7G_z$ exposure, the maximal QRS vector, in the sagittal plane, demonstrated an anterior shift. During the last 10 s of $+7G_z$ exposure, the directional changes in the maximal QRS vectors in the sagittal plane were reversed in relation to the early $+7G_z$ point. While the exact mechanisms involved in these changes are not clear, they may be related to the combination of the $+G_z$ stress, the exhaustive straining maneuvers (M-1 or L-1) necessary for the maintenance of vision, and the resulting high interpleural pressures. In relation to VCG alterations, it is not possible to determine the relative importance of the increased G field vs. the increased anti-G suit pressures and forces of straining involved with $+7G_z$ exposure for extended periods of time ($\geq$15 s).

Cohen et al. (9) reported T-vector angle changes in the frontal plane which resulted in a large increase in the QRS-T angle. The reported T-vector shifts were in the superior direction. Similar frontal plane maximal T-vector shifts were seen during the last 10 s of exposure to $+3G_z$, $+5G_z$, and $+7G_z$, with the magnitude of the shift increasing as $+G_z$ increased (Tables 6 and 7). However, none of the T angle or QRS-T angle changes observed in the frontal plane in the present study were statistically significant.

T-wave inversions were observed in the scalar leads during $+G_z$ exposure in only 2 of the 10 subjects, while the other subjects exhibited decreased T-wave voltages. These T-wave changes are reflected in changes in maximal T-vector magnitudes presented in Table 6. The rapid onset of these changes in the maximal T vector during $+G_z$ exposure and the rapid return to control values after $+G_z$ exposure imply that these T-wave changes are related to the strong sympathetic reflex changes induced by the acceleration stress and/or mechanical changes. Similar conclusions have been reported previously (7 - 9, 18).

Of particular interest is the comparison of the results of this study with the VCG changes reported in earlier studies. Three studies, reviewed by Gillingham and Crump (14), reported changes in the T-loops of VCGs recorded from subjects after $+G_z$ exposures. Two of the studies (Forlini's, and High Acceleration Cockpit program) showed increases in the sagittal-plane T-angles, while the other study (Lightweight Fighter program pilots) demonstrated decreases. Gillingham and Crump (14) concluded that the data available at that time indicated only that $+G_z$ stress resulted in "innocuous variability rather than an ominous consistency of T-loop changes in VCGs recorded following $+G_z$ stress." Although the sagittal plane T-angles in this study were increased 15 min after $+5G_z$ exposure, they were decreased after $+7G_z$ exposure. None of these changes were statistically significant. Thus, our results agree with the picture of inconsistent $+G_z$-related variations which emerged from the previous VCG studies.

In conclusion, the VCGs recorded during our 45-s exposures of human subjects to $+3G_z$, $+5G_z$, and $+7G_z$ stress demonstrated no changes indicative of myocardial ischemia and/or damage. Detailed review of the scalar ECG leads revealed neither significant abnormalities nor indications of conduction disturbances or ischemic ST-T segment changes. The major VCG alterations observed, during $+G_z$, appeared to be related to rotational changes of the heart due to mechanical stress and/or motion within the thorax. This relationship was exhibited as posterior rotation of the QRS axis in the sagittal plane and counterclockwise rotation of the QRS axis in the transverse plane. All changes in the VCGs and ECGs observed during $+G_z$ stress were gone 15 min after $+G_z$ exposure.

## REFERENCES


1. Bondurant, S., and W. A. Finnery. The spatial vectorcardiogram during acceleration. Aviat Med 29:758-672 (1958).

2. Brown, M. R., and J. T. Fitzsimmons. Electrocardiographic changes during positive acceleration. Br Heart J 21:21-30 (1959).

3. Burns, J. W., et al. The pathophysiologic response of the miniature swine to repeated exposures of simulated air combat maneuvers (SACM), p. 5. Review of Air Force Sponsored Basic Research in Environmental and Acceleration Physiology, 1978. AFOSR Annual Meeting, Colo. Springs, Colo., 12-13 Sep 1978.

4. Burton, R. R., S. D. Leverett, and E. D. Michaelson. Man at high, sustained $+G_z$ acceleration: A Review. Aerosp Med 45:1115-1136 (1974). [Now: Aviat Space Environ Med]

REFERENCES (Cont'd.)


5. Burton, R. R., and W. F. MacKenzie. Cardiac pathology associated with high sustained $+G_z$: I. Subendocardial hemorrhage. Aviat Space Environ Med 47:711-717 (1967).

6. Chou, T., R. A. Helm, and S. Kaplan. Clinical vectorcardiography. New York: Grume and Stratton, 1974.

7. Cohen, G. H., and W. K. Brown. Changes in ECG contour during prolonged $+G_z$ acceleration. Aerosp Med 40:874-879 (1969).

8. Cohen, G. H., and W. K. Brown. Electrocardiographic changes during positive acceleration. J Appl Physiol 27:858-862 (1969).

9. Cohen, G. H., et al. Analysis of the Frank orthogonal vectorcardiogram during gravitational stress. Aerosp Med 41:891-896 (1970).

10. Eliot, R. S., F. S. Everhart, and L. P. Sterns. Loops for the lost. Arch Intern Med 120:293-298 (1967).

11. Forker, A. D., H. Starke, and R. S. Eliot. Loop logic: An introduction to vectorcardiography. Geriatrics 87-95 (June 1975).

12. Frank, E. An accurate, clinically practical system for spatial vectorcardiography. Circulation 13:737-748 (1956).

13. Gillingham, K. K. Absence of high-G stress cardiopathy in a human centrifuge rider. SAM-TR-78-17, May 1978.

14. Gillingham, K. K., and P. P. Crump. Changes in clinical cardiologic measurements associated with high $+G_z$ stress. Aviat Space Environ Med 47(7):726-733 (1976).

15. Keiser, H. N., et al. VCG measurement and display. SAM-TR-77-9, Jul 1977.

16. Laughlin, M. H., W. M. Witt, and W. F. MacKenzie. Use of vectorcardiography for the detection of $+G_z$-related cardiac pathology in miniature swine. Aviat Space Environ Med 49:972-975 (1978).

17. MacKenzie, W. F., R. R. Burton, and W. F. Butcher. Cardiac pathology associated with high sustained $+G_z$: II. Stress and cardiomyopathy. Aviat Space Environ Med 47:718-725 (1976).

18. Shubrooks, S. J. Changes in cardiac rhythm during sustained high levels of positive ($+G_z$) acceleration. Aerosp Med 43:1200-1206 (1972).

19. Witt, W. M., et al. Vectorcardiographic recordings from adult miniature swine during and immediately after exposure to high, sustained $+G_z$: acute and chronic findings, pp. 51-53. Preprints of Aerospace Medical Association Annual Scientific Meeting, New Orleans, La., 8-11 May 1978.

20. Womble, M. E., et al. USAFSAM ECG/VCG digitizing and averaging system. SAM-TR-76-31, Sep 1976.

21. Womble, M. E., et al. A computerized VCG measurement and display system. The 29th Annual Conference on Engineering in Medicine and Biology, Boston, Mass., Nov 1976.

TABLE 1. ACCELERATION EXPOSURE SCHEDULE

| Subjects | Exposures First | Exposures Second | Exposures Third |
|---|---|---|---|
| | | [$+G_z$] | |
| PS | 5 | 7 | 3 |
| LG[a] | 3 | 5 | - |
| DM | 3 | 5 | 7 |
| JW | 7 | 3 | 5 |
| HM | 7 | 5 | 3 |
| RC | 5 | 3 | 7 |
| SS | 3 | 7 | 5 |
| RR[b] | 5 | 3 | 7 |
| AM | 7 | 3 | 5 |
| JK[a] | 3 | 7 | - |

[a]Subjects did not complete the study. Although the VCGs and scalar ECGs from these subjects were reviewed, the resulting data were excluded from the statistical analysis.

[b]Subject was exposed to $+3G_z$ and $+7G_z$ for 45 s on the same day.

TABLE 2. VECTORCARDIOGRAPHIC VARIABLES ANALYZED

| Variables in Frontal, Left Sagittal, Transverse, and Eigenplane |
|---|
| Maximum T Vector |
| Maximum QRS Vector |
| T/QRS Vector |
| J Vector |
| M Vector |
| True QRS Angle |
| Maximum QRS Angle |
| Maximum T Angle |
| QRS-T Angle |

| Variables from X, Y, and Z Coordinates |
|---|
| Scalar R Wave |
| Scalar T Wave |
| Scalar T/R Wave |
| Scalar J Junction |
| 40 msec Slope |

| Other Variables | |
|---|---|
| T Duration | Rotation Vector X |
| QRS Duration | Rotation Vector Y |
| QT Duration | Rotation Vector Z |
| Heart Rate | Rotation Vector Theta |

TABLE 3. PROBABILITIES FROM COMPARISONS OF PREACCELERATION (ORDER) MEANS

| Variable | Frontal | Sagittal | Transverse | Eigenplane |
|---|---|---|---|---|
| Max T Vector | [a] | | .031 | |
| T/QRS Vector | | | | |
| True QRS Angle | | | | |
| Max QRS Angle | | | | |
| Max T Angle | | | | |
| QRS-T Angle | | | | |
| Max QRS Vector | | | | |
| J Vector | | .039 | | .019 |
| M Vector | | .030 | .002 | .012 |

| | Coordinates | | |
|---|---|---|---|
| Variable | X | Y | Z |
| R Wave | | | |
| T Wave | | | .041 |
| T Duration | | | |
| T/R Wave | | | |
| J Junction | | | .007 |
| 40 msec Slope | | .022 | |

Other Variables

| Variable | Probability |
|---|---|
| T Duration | .049 |
| QT Duration | .029 |
| QRS Duration | |
| Heart Rate | |
| Rot Vec X | |
| Rot Vec Y | |
| Rot Vec Z | .040 |
| Rot Vec Theta | |

---

[a]A blank signifies that the means are not different at the .05 level.
Max = maximum
Rot Vec = Rotation Vector

## TABLE 4. PREACCELERATION (ORDER) MEANS AND TESTS AGAINST CONTROL

| Variable | Exposures 1 | 2 | 3 | 1 | 2 | 3 |
|---|---|---|---|---|---|---|
| | **Frontal Plane** | | | **Sagittal Plane** | | |
| Max T Vector | .296 | .313 | .369 | .310 | .361 | .420 |
| T/QRS Vector | .1841 | .2001 | .2089 | .2617 | .3031 | .2986 |
| True QRS Angle | 45.7 | 43.4 | 46.9 | 127.9 | 129.4 | 125.6 |
| Max QRS Angle | 42.0 | 44.4 | 45.7 | 128.7 | 117.3 | 118.1 |
| Max T Angle | 40.0 | 48.1 | 41.3 | 30.4 | 37.6 | 32.1 |
| QRS-T Angle | -2.0 | 3.7 | -4.4 | -98.3 | -79.7 | -86.0 |
| Max QRS Vector | 1.649 | 1.711 | 1.859 | 1.326 | 1.410 | 1.503 |
| J Vector | .033 | .037 | .037 | .050 | .061 | .074[a] |
| M Vector | .046 | .043 | .047 | .093 | .113 | .120[a] |
| | **Transverse Plane** | | | **Eigenplane** | | |
| Max T Vector | .356 | .380 | .461[a] | .391 | .429 | .511 |
| T/QRS Vector | .2681 | .2946 | .3223 | .2304 | .2611 | .2716 |
| True QRS Angle | -37.9 | -37.3 | -37.6 | 90.0 | 90.0 | 90.0 |
| Max QRS Angle | -26.6 | -26.6 | -40.4 | 79.6 | 80.3 | 81.0 |
| Max T Angle | 50.3 | 58.6 | 52.1 | 15.7 | 16.1 | 17.3 |
| QRS-T Angle | 76.9 | 85.4 | 92.6 | -63.9 | -64.1 | -63.7 |
| Max QRS Vector | 1.347 | 1.419 | 1.496 | 1.767 | 1.860 | 1.984 |
| J Vector | .047 | .060 | .067 | .046 | .059 | .073[b] |
| M Vector | .090 | .107[a] | .117[b] | .097 | .113 | .124[b] |
| | **X Lead** | | | **Y Lead** | | |
| R Wave | 1.190 | 1.236 | 1.266 | 1.136 | 1.216 | 1.314 |
| T Wave | .233 | .221 | .274 | .174 | .210 | .230 |
| T/R Wave | .1934 | .1899 | .2149 | .1689 | .1973 | .1950 |
| J Junction | .006 | -.009 | .014 | .020 | .009 | .027 |
| 40 msec Slope | .417 | .420 | .296 | -.029 | .491[b] | .130 |
| | **Z Lead** | | | | | |
| R Wave | .340 | .336 | .400 | | | |
| T Wave | .263 | .301 | .354[a] | | | |
| T/R Wave | .9754 | 1.1551 | 1.0829 | | | |
| J Junction | .039 | .054 | .064[b] | | | |
| 40 msec Slope | 1.136 | 1.230 | 1.219 | | | |

| Variable | Exposures 1 | 2 | 3 |
|---|---|---|---|
| | **Other Variables** | | |
| T Duration | 266.79 | 287.86[a] | 270.36 |
| QT Duration | 355.71 | 381.43[a] | 362.14 |
| QRS Duration | 88.93 | 93.57 | 91.79 |
| Heart Rate | 78.97 | 75.13 | 74.67 |
| Rot Vec X | -.101 | -.390 | -.261 |
| Rot Vec Y | .614 | .411 | .540 |
| Rot Vec Z | .511 | .603[a] | .550 |
| Rot Vec Theta | 119.4 | 125.9 | 122.1 |

[a]Mean differs from the (order) mean at the .05 level.
[b]Mean differs from the (order) mean at the .01 level.
Max = maximum
Rot Vec = Rotation Vector

## TABLE 5. PROBABILITIES FROM THE ANALYSES OF DURING $+G_z$ DATA

| | Exposures | | | | | |
|---|---|---|---|---|---|---|
| Variable | Time | G-Level | G-Level by time | Time | G-Level | G-Level by time |
| | Frontal Plane | | | Sagittal Plane | | |
| Max T Vector | <.001 | | .001 | <.001 | | <.001 |
| Max QRS Vector | .002 | | <.001 | | | |
| T/QRS Vector | .014 | | .002 | .004 | | .030 |
| J Vector | | .038 | .038 | | | |
| M Vector | <.001 | | <.001 | <.001 | | <.001 |
| True QRS Angle | | | | <.001 | | |
| Max QRS Angle | | | .029 | | | |
| Max T Angle | | | | .041 | | |
| QRS-T Angle | | | | .013 | | |
| | Transverse Plane | | | Eigenplane | | |
| Max T Vector | <.001 | | <.001 | <.001 | | <.001 |
| Max QRS Vector | | | | | | |
| T/QRS Vector | <.001 | | .009 | .004 | | .010 |
| J Vector | | | | | | |
| M Vector | <.001 | | <.001 | <.001 | | <.001 |
| True QRS Angle | <.001 | .004 | <.001 | | | |
| Max QRS Angle | | | | .044 | | |
| Max T Angle | | | | .017 | | |
| QRS-T Angle | | | .042 | | | |
| | X Lead | | | Y Lead | | |
| R Wave | .001 | | <.001 | .007 | | |
| T Wave | .004 | | .009 | .002 | | |
| T/R Wave | | | | | | |
| J Junction | | .021 | | .012 | .002 | .003 |
| 40 msec Slope | | .002 | | | | |
| | Z Lead | | | | | |
| R Wave | <.001 | | <.001 | | | |
| T Wave | .001 | | .021 | | | |
| T/R Wave | <.001 | .024 | .011 | | | |
| J Junction | | | | | | |
| 40 msec Slope | | | | | | |

| | Exposures | | |
|---|---|---|---|
| Variable | Time | G-Level | G-Level by time |
| | Other Variables | | |
| T Duration | <.001 | .014 | <.001 |
| QRS Duration | | | |
| Q-T Duration | <.001 | .024 | <.001 |
| Heart Rate | <.001 | <.001 | <.001 |
| Rot Vec X | | | |
| Rot Vec Y | | | |
| Rot Vec Z | | | |
| Rot Vec Theta | | | |

Max = maximum
Rot Vec = Rotation Vector

## TABLE 6. VECTOR AMPLITUDE MEANS (mV) TESTS AGAINST BEFORE $+G_z$

### A. Frontal Plane

**Max T Vector**

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | .352 | .319 | .292 |
| Early | .211[b] | .180[b] | .386[a] |
| Late | .264[a] | .214[a] | .347 |
| 1 Min Post | .370 | .457[b] | .556[b] |
| 5 Min Post | .336 | .337 | .329 |
| 15 Min Post | .356 | .336 | .302 |

**Max QRS Vector**

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | 1.752 | 1.697 | 1.709 |
| Early | 1.754 | 1.610 | 1.459[b] |
| Late | 1.784 | 1.544[b] | 1.385[b] |
| 1 Min Post | 1.777 | 1.704 | 1.675 |
| 5 Min Post | 1.809 | 1.797 | 1.826[a] |
| 15 Min Post | 1.820 | 1.791 | 1.801 |

**T/QRS Vector**

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | .2164 | .1957 | .1756 |
| Early | .1330[a] | .1116[a] | .3624[b] |
| Late | .1750 | .1493 | .2713[a] |
| 1 Min Post | .2259 | .2787[a] | .3445[b] |
| 5 Min Post | .2042 | .1980 | .1882 |
| 15 Min Post | .2084 | .1942 | .1736 |

**J Vector**

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | .035 | .036 | .026 |
| Early | .035 | .068 | .051 |
| Late | .044 | .099[b] | .148[b] |
| 1 Min Post | .035 | .061 | .098[b] |
| 5 Min Post | .050 | .086[a] | .032 |
| 15 Min Post | .050 | .048 | .043 |

**M Vector**

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | .045 | .044 | .039 |
| Early | .029 | .080[b] | .084[b] |
| Late | .044 | .100[b] | .117[b] |
| 1 Min Post | .041 | .050 | .066[a] |
| 5 Min Post | .046 | .025 | .032 |
| 15 Min Post | .052 | .046 | .047 |

### B. Sagittal Plane

**Max T Vector**

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | .359 | .394 | .334 |
| Early | .226[b] | .252[b] | .450[b] |
| Late | .291 | .355 | .384 |
| 1 Min Post | .376 | .538[b] | .591[b] |
| 5 Min Post | .349 | .384 | .335 |
| 15 Min Post | .372 | .374 | .327 |

**Max QRS Vector**

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | 1.356 | 1.449 | 1.426 |
| Early | 1.307 | 1.484 | 1.377[b] |
| Late | 1.306 | 1.409 | 1.530 |
| 1 Min Post | 1.360 | 1.446 | 1.437 |
| 5 Min Post | 1.395 | 2.305 | 1.522 |
| 15 Min Post | 1.441 | 1.650 | 1.423 |

**T/QRS Vector**

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | .2967 | .2945 | .2597 |
| Early | .1902 | .1637[a] | .4448[b] |
| Late | .2566 | .2648 | .2806 |
| 1 Min Post | .3026 | .3912[a] | .4543[b] |
| 5 Min Post | .2769 | .2052 | .2467 |
| 15 Min Post | .2824 | .2520 | .2412 |

**J Vector**

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | .056 | .065 | .050 |
| Early | .051 | .061 | .052 |
| Late | .069 | .101 | .153 |
| 1 Min Post | .045 | .071 | .092 |
| 5 Min Post | .060 | .107 | .039 |
| 15 Min Post | .069 | .073 | .048 |

**M Vector**

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | .105 | .111 | .095 |
| Early | .085 | .085[a] | .127[b] |
| Late | .101 | .138[a] | .165[b] |
| 1 Min Post | .094 | .105 | .112 |
| 5 Min Post | .100 | .076[b] | .077 |
| 15 Min Post | .110 | .100 | .083 |

[a]Differs from the Before G mean at the .05 level.
[b]Differs from the Before G mean at the .01 level.
Max = maximum

TABLE 6 (CONT'D.)

C. Transverse Plane

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| **Max T Vector** | | | |
| Before | .399 | .415 | .366 |
| Early | .265[b] | .256[b] | .396 |
| Late | .321[a] | .343 | .364 |
| 1 Min Post | .394 | .545[b] | .621[b] |
| 5 Min Post | .374 | .400 | .364 |
| 15 Min Post | .416 | .387 | .368 |
| **T/QRS Vector** | | | |
| Before | .3177 | .3272 | .2707 |
| Early | .2074[b] | .1996[b] | .3607[a] |
| Late | .2571 | .2555 | .2615 |
| 1 Min Post | .3146 | .3983 | .4364[b] |
| 5 Min Post | .3025 | .2351[a] | .2576 |
| 15 Min Post | .3245 | .2820 | .2820 |
| **M Vector** | | | |
| Before | .099 | .105 | .096 |
| Early | .081 | .062[b] | .120[a] |
| Late | .095 | .099[a] | .135[b] |
| 1 Min Post | .085 | .101 | .104 |
| 5 Min Post | .092 | .072[b] | .074[a] |
| 15 Min Post | .104 | .098 | .085 |

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| **Max QRS Vector** | | | |
| Before | 1.387 | 1.290 | 1.415 |
| Early | 1.414 | 1.279 | 1.328 |
| Late | 1.467 | 1.324 | 1.526 |
| 1 Min Post | 1.400 | 1.325 | 1.481 |
| 5 Min Post | 1.391 | 2.115 | 1.481 |
| 15 Min Post | 1.396 | 1.525 | 1.344 |
| **J Vector** | | | |
| Before | .056 | .059 | .046 |
| Early | .050 | .049 | .063 |
| Late | .062 | .066 | .088 |
| 1 Min Post | .045 | .060 | .060 |
| 5 Min Post | .052 | .104 | .031 |
| 15 Min Post | .060 | .074 | .045 |

D. Eigenplane

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| **Max T Vector** | | | |
| Before | .451 | .462 | .402 |
| Early | .277[b] | .269[b] | .494 |
| Late | .349[a] | .379 | .433 |
| 1 Min Post | .465 | .632[b] | .722[b] |
| 5 Min Post | .429 | .459 | .415 |
| 15 Min Post | .465 | .445 | .400 |
| **T/QRS Vector** | | | |
| Before | .2655 | .2687 | .2267 |
| Early | .1685 | .1483[a] | .4380[b] |
| Late | .2225 | .2287 | .2780 |
| 1 Min Post | .2727 | .3605[a] | .4103[b] |
| 5 Min Post | .2526 | .1999 | .2211 |
| 15 Min Post | .2645 | .2332 | .2197 |
| **M Vector** | | | |
| Before | .106 | .114 | .099 |
| Early | .085 | .092[a] | .136[b] |
| Late | .104 | .141[a] | .182[b] |
| 1 Min Post | .094 | .110 | .115 |
| 5 Min Post | .100 | .076[b] | .080 |
| 15 Min Post | .112 | .105 | .089 |

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| **Max QRS Vector** | | | |
| Before | 1.847 | 1.805 | 1.855 |
| Early | 1.834 | 1.750 | 1.654 |
| Late | 1.867 | 1.700 | 1.785 |
| 1 Min Post | 1.861 | 1.796 | 1.848 |
| 5 Min Post | 1.884 | 2.617 | 1.970 |
| 15 Min Post | 1.905 | 2.038 | 1.864 |
| **J Vector** | | | |
| Before | .054 | .064 | .046 |
| Early | .057 | .072 | .060 |
| Late | .067 | .106 | .163 |
| 1 Min Post | .046 | .076 | .100 |
| 5 Min Post | .062 | .119 | .042 |
| 15 Min Post | .070 | .079 | .048 |

[a]Differs from the Before G mean at the .05 level.
[b]Differs from the Before G mean at the .01 level.
Max = maximum

### TABLE 7. VECTOR ANGLE (DEGREES) MEANS AND TESTS AGAINST BEFORE $+G_z$

#### A. Frontal Plane

True QRS Angle

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | 46.1 | 50.6 | 48.8 |
| Early | 44.9 | 56.4 | 66.8 |
| Late | 44.4 | 41.0 | 43.5 |
| 1 Min Post | 46.5 | 46.6 | 52.9 |
| 5 Min Post | 48.9 | 49.9 | 49.3 |
| 15 Min Post | 49.9 | 50.1 | 52.0 |

Max QRS Angle

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | 44.9 | 49.3 | 44.0 |
| Early | 44.0 | 51.0 | 49.0[b] |
| Late | 42.8 | 46.2 | 49.9[b] |
| 1 Min Post | 45.6 | 46.8 | 44.8 |
| 5 Min Post | 46.6 | 48.5 | 46.0 |
| 15 Min Post | 47.5 | 47.7 | 45.6 |

Max T Angle

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | 41.8 | 44.0 | 44.3 |
| Early | 31.5 | 50.4 | 13.4 |
| Late | 34.1 | 16.2 | 14.1 |
| 1 Min Post | 44.1 | 45.0 | 41.9 |
| 5 Min Post | 44.1 | 46.6 | 46.1 |
| 15 Min Post | 44.3 | 50.1 | 34.0 |

QRS-T Angle

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | -3.1 | -5.3 | .3 |
| Early | -12.5 | -.6 | -35.6 |
| Late | -8.6 | -30.0 | -35.8 |
| 1 Min Post | -1.5 | -1.8 | -2.9 |
| 5 Min Post | -2.5 | -1.9 | .1 |
| 15 Min Post | -3.3 | 2.4 | -11.7 |

#### B. Sagittal Plane

True QRS Angle

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | 122.0 | 122.9 | 127.4 |
| Early | 122.7 | 134.6 | 150.8 |
| Late | 121.7 | 123.6 | 95.6 |
| 1 Min Post | 120.4 | 134.1 | 143.0 |
| 5 Min Post | 116.5 | 128.7 | 129.5 |
| 15 Min Post | 114.4 | 121.8 | 118.4 |

Max QRS Angle

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | 110.8 | 110.1 | 126.0 |
| Early | 109.9 | 136.9 | 106.8 |
| Late | 111.1 | 137.0 | 142.1 |
| 1 Min Post | 108.5 | 78.3 | 122.8 |
| 5 Min Post | 107.0 | 88.4 | 116.9 |
| 15 Min Post | 106.5 | 112.4 | 110.4 |

Max T Angle

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | 34.91 | 30.4 | 34.1 |
| Early | 3.4 | 5.7 | 31.1 |
| Late | 13.4 | -11.5 | -.5 |
| 1 Min Post | 38.3 | 34.3 | 39.0 |
| 5 Min Post | 35.9 | 35.4 | 36.0 |
| 15 Min Post | 32.8 | 39.7 | 26.7 |

QRS-T Angle

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | -75.9 | -79.8 | -91.9 |
| Early | -106.5 | -131.2 | -75.7 |
| Late | -97.8 | -148.5 | -142.7 |
| 1 Min Post | -70.3 | -44.0 | -83.7 |
| 5 Min Post | -71.1 | -53.0 | -80.9 |
| 15 Min Post | -73.8 | -72.7 | -83.7 |

[a]Differs from the Before G mean at the .05 level.
[b]Differs from the Before G mean at the .01 level.
Max = maximum

TABLE 7 (Cont'd.)

## C. Transverse Plane

True QRS Angle

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | -31.6 | -37.8 | -38.9 |
| Early | -36.0 | -53.2[b] | -70.8[b] |
| Late | -29.1 | -54.6[b] | -75.0[b] |
| 1 Min Post | -29.9 | -45.3 | -57.6[b] |
| 5 Min Post | -27.8 | -43.8 | -44.3 |
| 15 Min Post | -28.0 | -35.7 | -29.9[a] |

Max QRS Angle

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | -33.9 | -37.9 | -38.9 |
| Early | -32.9 | -37.4 | -70.7 |
| Late | -32.4 | -52.2 | -64.1 |
| 1 Min Post | -33.4 | -37.8 | -57.7 |
| 5 Min Post | -33.3 | -45.6 | -37.6 |
| 15 Min Post | -33.8 | -37.6 | -33.5 |

Max T Angle

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | 47.8 | 56.5 | 57.8 |
| Early | 41.0 | 59.2 | 91.0 |
| Late | 48.4 | 47.7 | 32.3 |
| 1 Min Post | 48.5 | 54.0 | 53.8 |
| 5 Min Post | 49.8 | 53.1 | 54.3 |
| 15 Min Post | 52.0 | 57.9 | 51.0 |

QRS-T Angle

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | 81.6 | 94.4 | 96.6 |
| Early | 73.9 | 96.6 | 161.7[b] |
| Late | 80.8 | 99.9 | 96.5 |
| 1 Min Post | 81.9 | 91.8 | 115.5 |
| 5 Min Post | 83.0 | 98.8 | 91.9 |
| 15 Min Post | 85.8 | 95.6 | 84.4 |

## D. Eigenplane

Max QRS Angle

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | 80.6 | 78.5 | 78.0 |
| Early | 77.4 | 71.8 | 60.4 |
| Late | 79.0 | 71.2 | 84.7 |
| 1 Min Post | 79.8 | 72.5 | 64.9 |
| 5 Min Post | 81.5 | 80.4 | 74.5 |
| 15 Min Post | 83.4 | 83.4 | 80.3 |

Max T Angle

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | 24.0 | 14.4 | 15.6 |
| Early | 14.3 | -5.7 | -26.0 |
| Late | 15.1 | -3.5 | 14.2 |
| 1 Min Post | 26.4 | 10.3 | 2.5 |
| 5 Min Post | 26.9 | -5.9 | 12.8 |
| 15 Min Post | 24.9 | 16.6 | 22.2 |

QRS-T Angle

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | -56.8 | -64.1 | -62.4 |
| Early | -63.1 | -77.5 | -86.4 |
| Late | -63.9 | -74.7 | -70.5 |
| 1 Min Post | -53.4 | -62.2 | -62.4 |
| 5 Min Post | -54.6 | -86.3 | -61.8 |
| 15 Min Post | -58.5 | -66.8 | -58.0 |

[a]Differs from the <u>Before G</u> mean at the .05 level.
[b]Differs from the <u>Before G</u> mean at the .01 level.
Max = maximum

## TABLE 8. THE MEANS OF SCALAR LEADS AND TESTS AGAINST BEFORE $+G_z$

### A. X Lead

R Wave

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | 1.230 | 1.090 | 1.184 |
| Early | 1.272 | .966[a] | .948[b] |
| Late | 1.331 | 1.025 | .938[b] |
| 1 Min Post | 1.252 | 1.133 | 1.170 |
| 5 Min Post | 1.244 | 1.162 | 1.246 |
| 15 Min Post | 1.236 | 1.177 | 1.218 |

T/R Wave

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | .2502 | .2030 | .1969 |
| Early | .1590 | .0973 | .1947 |
| Late | .1960 | .1377 | .1900 |
| 1 Min Post | .2446 | .2711 | .3680 |
| 5 Min Post | .2290 | .2001 | .1871 |
| 15 Min Post | .2376 | .1916 | .2019 |

40 msec Slope

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | .284 | .352 | .524 |
| Early | .144 | .524 | 1.227 |
| Late | .105 | .786 | 1.469 |
| 1 Min Post | .169 | .545 | 1.160 |
| 5 Min Post | .104 | 1.230 | .372 |
| 15 Min Post | .232 | .383 | .395 |

T Wave

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | .269 | .227 | .216 |
| Early | .174[a] | .097[b] | .111[b] |
| Late | .204 | .130[b] | .159 |
| 1 Min Post | .262 | .309[a] | .410[a] |
| 5 Min Post | .247 | .236 | .219 |
| 15 Min Post | .269 | .228 | .239 |

J Junction

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | .004 | .009 | -.002 |
| Early | .006 | -.040 | -.035 |
| Late | .006 | -.035 | -.053 |
| 1 Min Post | .011 | -.028 | -.049 |
| 5 Min Post | .019 | -.046 | -.012 |
| 15 Min Post | .017 | .013 | .021 |

### B. Y Lead

R Wave

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | 1.217 | 1.301 | 1.197 |
| Early | 1.191 | 1.258 | 1.122 |
| Late | 1.179 | 1.117 | 1.030 |
| 1 Min Post | 1.236 | 1.272 | 1.165 |
| 5 Min Post | 1.276 | 1.375 | 1.314 |
| 15 Min Post | 1.321 | 1.343 | 1.292 |

T/R Wave

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | .2021 | .1806 | .1651 |
| Early | .1045 | .0759 | .2676 |
| Late | .1442 | .0778 | .1405 |
| 1 Min Post | .2211 | .2710 | .3611 |
| 5 Min Post | .1930 | .1894 | .1916 |
| 15 Min Post | .1815 | .1883 | .1599 |

T Wave

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | .220 | .216 | .179 |
| Early | .104 | .070 | .222 |
| Late | .131 | .037 | .125 |
| 1 Min Post | .246 | .317 | .381 |
| 5 Min Post | .221 | .235 | .222 |
| 15 Min Post | .220 | .242 | .190 |

J Junction

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| Before | .024 | .008 | .019 |
| Early | .007 | -.050[b] | -.013 |
| Late | .005 | -.069[b] | -.135[b] |
| 1 Min Post | .021 | -.041[a] | -.069[b] |
| 5 Min Post | .032 | -.040[a] | -.010 |
| 15 Min Post | .035 | .027 | .044 |

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[a]Differs from the Before G mean at the .05 level.
[b]Differs from the Before G mean at the .01 level.
Max = maximum

TABLE 8: B. THE Y LEAD (CONT'D.)

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| | 40 msec Slope | | |
| Before | .230 | .192 | .175 |
| Early | -.171 | .169 | .124 |
| Late | -.025 | .175 | 1.653 |
| 1 Min Post | .217 | .673 | 1.209 |
| 5 Min Post | -.011 | .955 | .030 |
| 15 Min Post | -.007 | .343 | -.468 |

C. Z Lead

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| | P Wave | | |
| Before | .382 | .422 | .389 |
| Early | .370 | .318[b] | .197[b] |
| Late | .381 | .302[b] | .194[b] |
| 1 Min Post | .371 | .415 | .368 |
| 5 Min Post | .387 | .417 | .402 |
| 15 Min Post | .450[a] | .412 | .459[a] |
| | T/P Wave | | |
| Before | .9752 | .9861 | 1.0145 |
| Early | .7242 | .9852 | 1.6588[b] |
| Late | .9164 | 1.5205[b] | 1.5124[b] |
| 1 Min Post | .9810 | 1.3405[a] | 1.6546[b] |
| 5 Min Post | .8999 | .7706 | .8917 |
| 15 Min Post | .8082 | .8704 | .7669 |
| | 40 msec Slope | | |
| Before | 1.186 | 1.162 | 1.164 |
| Early | .985 | .927 | 1.529 |
| Late | .940 | 1.190 | 1.657 |
| 1 Min Post | 1.166 | 1.240 | 1.481 |
| 5 Min Post | 1.239 | 2.752 | 1.125 |
| 15 Min Post | 1.242 | 1.314 | 1.012 |

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|
| | T Wave | | |
| Before | .289 | .337 | .287 |
| Early | .182[a] | .213[b] | .364 |
| Late | .249 | .293 | .260 |
| 1 Min Post | .290 | .440[a] | .459[b] |
| 5 Min Post | .277 | .202[b] | .270 |
| 15 Min Post | .305 | .278 | .280 |
| | J Junction | | |
| Before | .047 | .054 | .045 |
| Early | .039 | .008 | .028 |
| Late | .054 | .034 | .027 |
| 1 Min Post | .036 | .044 | .037 |
| 5 Min Post | .040 | .040 | .024 |
| 15 Min Post | .050 | .039 | .038 |

[a]Differs from the Before G mean at the .05 level.
[b]Differs from the Before G mean at the .01 level.
Max = maximum

TABLE 9. DURATIONS AND HEART RATES DURING $+G_z$

| Time | T Duration | | | QRS Duration | | | Q-T Duration | | | Heart Rate | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $+3G_z$ | $+5G_z$ | $+7G_z$ | $+3G_z$ | $+5G_z$ | $+7G_z$ | $+3G_z$ | $+5G_z$ | $+7G_z$ | $+3G_z$ | $+5G_z$ | $+7G_z$ |
| Before | 288 | 273 | 281 | 91 | 93 | 90 | 379 | 366 | 371 | 68 | 77 | 80 |
| Early | 303 | 242[a] | 223[b] | 90 | 96 | 90 | 393 | 338[a] | 313[b] | 92[b] | 141[b] | 161[b] |
| Late | 302 | 211[b] | 185[b] | 88 | 93 | 93 | 390 | 304[b] | 278[b] | 83[b] | 140[b] | 170[b] |
| 1 Min Post | 291 | 251 | 236[b] | 89 | 94 | 95 | 380 | 345 | 331[b] | 66 | 69 | 83 |
| 5 Min Post | 298 | 299[a] | 292 | 89 | 83 | 94 | 388 | 382 | 387 | 65 | 68 | 76 |
| 15 Min Post | 297 | 309[b] | 278 | 92 | 87 | 89 | 388 | 396[a] | 367 | 65 | 75 | 78 |

Means are presented in milliseconds for the durations, and in beats per min for the heart rates.
[a]Differs from the Before G mean at the .05 level.
[b]Differs from the Before G mean at the .01 level.

TABLE 10. THE MEANS OF ROTATION VECTORS

| Time | $+3G_z$ | $+5G_z$ | $+7G_z$ | | Time | $+3G_z$ | $+5G_z$ | $+7G_z$ |
|---|---|---|---|---|---|---|---|---|
| | Vector X | | | | | Vector Y | | |
| Before | -.429 | -.340 | -.194 | | Before | .397 | .484 | .531 |
| Early | -.179 | -.312 | -.082 | | Early | .564 | .566 | .706 |
| Late | -.169 | -.249 | -.209 | | Late | .567 | .581 | .431 |
| 1 Min Post | -.294 | -.475 | -.488 | | 1 Min Post | .487 | .358 | .273 |
| 5 Min Post | -.425 | -.330 | -.437 | | 5 Min Post | .435 | .387 | .342 |
| 15 Min Post | -.179 | -.517 | -.056 | | 15 Min Post | .601 | .313 | .677 |
| | Vector Z | | | | | Vector Theta | | |
| Before | .571 | .552 | .546 | | Before | 129.4 | 126.0 | 125.7 |
| Early | .519 | .495 | .571 | | Early | 127.0 | 122.1 | 132.8 |
| Late | .524 | .525 | .512 | | Late | 127.1 | 121.7 | 126.3 |
| 1 Min Post | .549 | .571 | .575 | | 1 Min Post | 126.5 | 125.2 | 128.6 |
| 5 Min Post | .551 | .429 | .565 | | 5 Min Post | 130.5 | 117.9 | 131.2 |
| 15 Min Post | .509 | .549 | .471 | | 15 Min Post | 124.7 | 125.9 | 125.5 |

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